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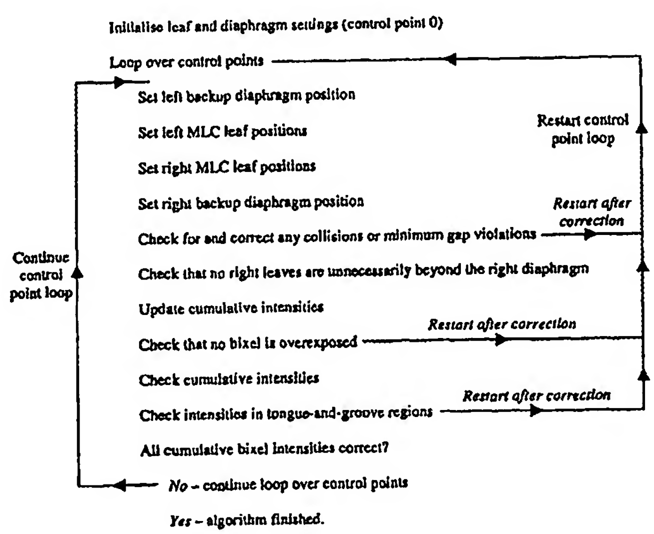

(57) Abstract

An algorithm to generate discrete beam intensity modulation by dynamic multileaf collimation (MLC) is described which incorporates constraints on minimum allowed leaf separations. MLC positioning information is derived simultaneously for all leaf pairs and backup diaphragms as they progress across the field and a feedback mechanism allows corrections to be applied to eliminate potential violations of minimum separation conditions and any underexposure in the inter-leaf-tongue-and-groove region as they are encountered. The resulting motion correctly delivers the intended modulation and is physically realisable. Results of the algorithm can also alternatively be interpreted as defining a series of static fields to deliver the same modulation.

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CONTROLLING DELIVERY OF RADIOTHERAPY

The present invention relates to a method of controlling the delivery of radiotherapy. It uses a multileaf collimator to deliver radiation doses which vary over the treatment area.

A number of authors have described how intensity-modulated fields for conformal radiotherapy can be implemented by either dynamic multileaf collimation (for example, Källman *et al* (1988), Convery and Rosenbloom (1992), Spirou and Chui (1994), Stein *et al* (1994), Svensson *et al* (1994), Yu *et al* (1995), van Santvoort and Heijmen (1996) Hill *et al* (1997)) or by multiple static fields (for example, Galvin *et al* (1993), Bortfield *et al* (1994).

US 5663999 discloses a method in which the treatment area is divided into a plurality of sections which are treated individually.

It will be clear that the quickest way to achieve a variable dose treatment would be to irradiate various parts of the treatment area simultaneously. The system of US 5663999 is unable to do so, although it notes that treatment time is a factor which will ideally be reduced. However, it has hitherto been difficult or impossible to provide an algorithm able to deliver any treatment profile, for the simple reason that the multi-leaf collimators available at present must maintain a minimum leaf separation of (for example) 1 centimetre. As a dynamic treatment pattern evolves, it may be necessary to blank off parts of the treatment area in a way which calls

for leaves to touch. Thus, some treatment profiles cannot be delivered, preventing widespread application of this technique.

The present invention provides a method of delivering a radiotherapy treatment using a linear accelerator,

the linear accelerator comprising a source of radiation, the output of which is limited by a multi-leaf collimator and a further collimator comprising at least two diaphragms;

the method comprising the steps of:

notionally dividing the treatment area into an array of cells distributed along lines parallel to the movement directions of the leaves;

assigning an intended dose to each cell;

during irradiation, adjusting the position of the leaves so as to provide the intended dose to each cell, wherein during irradiation, the diaphragms are advanced beyond one or more leaves when necessary to maintain leaf separation and prevent overdosing.

Thus, according to the present invention, the diaphragms are normally maintained behind the outermost leaf, but are on occasions advanced beyond one or more leaves so that they provide the primary shield against dosing. This effectively permits one or more leaves to be withdrawn, allowing an opposing leaf to be advanced so as to limit dosage without infringing minimal leaf separation.

It is good practice to keep the diaphragm immediately behind or close behind the outermost leaves. This is because multi-leaf collimators are somewhat leaky and therefore the diaphragm will limit some leakage.

In this application, it is assumed that leaves on the left of the field are extended as leaves on the right are withdrawn. All directional detail is to be interpreted in this context. However, it will clearly be understood that the invention can be applied to a reversed situation.

An embodiment of the invention will now be described by way of example, with reference to the accompanying figures, in which;

Figures 1a and 1b show a typical discretely-intensity modulated beam;

Figure 2a and 2b illustrates the minimum leaf separation constraint;

Figure 3 illustrates the control point formulation;

Figure 4 shows a schematic flow diagram; and

Figure 5 illustrates the control point sequence to achieve the beam of Figures 1a and 1b.

A discretely-intensity-modulated beam is here taken to mean one which is divided into a number of smaller beam elements. Within each beam element the intensity is constant but each element may be at a different intensity level. An example is shown in Figure 1. This is for the posterior oblique field of a prostate plan with 10% intensity stratification and 1cm x 1cm beam elements at the isocentre plane, planned with Corvus planning system (example courtesy of NOMOS). Figure 1a shows the example in grey-scales and Figure 1b shows the intensity matrix. Beam elements hereafter referred to as "bixels" (by analogy with image pixels) typically measure 1cm x 1cm at the isocentre. Discrete beam intensity modulation is assumed by some inverse treatment planning systems.

Implementing discrete beam intensity modulation (BIM) by continuous dynamic multileaf collimation (DMLC) poses some unique problems. In particular, abrupt intensity changes are required between beam elements along the direction of leaf travel. Hill *et al* (1997) have previously shown that this can be achieved by combining the ramp down of intensity delivered across a bixel as a leading leaf moves across it at constant speed with the

corresponding ramp up delivered as the trailing leaf passes it with the same speed. A similar use of overlapping ramped intensity distributions was used by Davy and colleagues on the Tracking Cobalt Unit at the Royal Free Hospital, London (see for example Davy (1985)).

The algorithm presented by Hill *et al* (1997) is an extension of that used by Bortfield *et al* (1994) for generating discrete intensity-modulated beams by summing a series of static MLC fields. In these algorithms, the intensity profile along each leaf pair is examined independently. For each profile, rising and falling edges of the intensity pattern are paired to give a series of static fields, which can be ordered to give a unidirectional "sweep" of the leaves across the field. In the dynamic implementation, Hill *et al* (1997) transform this multiple static field sequence into a single dynamic sequence during which leaves can be either stationary or moving at the maximum allowed speed and the previously described ramp down and ramp up of intensity across bixels then overlap to give uniform bixel intensities. No consideration of tongue-and-groove artefacts (van Santvoort and Heijmen (1996)) is made in the algorithm.

The above dynamic scheme requires that the leaves can close to zero separation at the start and end of the sequence and also that a trailing leaf of one leaf pair can overlap an adjacent leading leaf on the opposite leaf bank. This is not possible on all multileaf collimators and indeed may not always be desirable due to the associated risk of mechanical collisions and the leakage through the touching rounded leaf ends used on some MLC designs.

For the multileaf collimator (MLC) produced by the applicants, the minimum allowed leaf separation in dynamic mode is set to 1cm with this restriction also applying to opposite but adjacent leaves so that no leaf overlap can occur. Referring to Figure 2(a), the most leading left leaf must not only maintain the necessary minimum separation with the opposite right

leaf but also with the right leaves above and below. The same minimum separation distance applies between the backup diaphragms. Projected to the isocentre, the MLC leaf width is 1.0cm and their range of travel is 20cm from the beam axis to 12.5cm over midline. The MLC's backup diaphragms have the same range of travel, while the collimator pair perpendicular to this can travel from 20cm from the beam axis up to midline. Details of the Elekta MLC and its characterisation for static field use has been given previously by Jordan and Williams (1994).

Dynamic control of the MLC leaves and diaphragms is specified in the algorithm described herein through the use of the "control point" formalism employed by the Elekta dynamic MLC control system. A control point specifies the machine configuration (field size and shape, gantry angle, etc.) at a particular percentage of the set beam monitor units (MU). By defining a sequence of control points associated with different percentage monitor units a dynamic delivery is defined, for example as shown in Figure 3. In the Elekta control system, the desired value of any parameter (e.g. an MLC leaf position) at any particular percentage monitor unit value is found by linear interpolation between the control points immediately before and after this percentage MU. By using percentage MU rather than actual beam MU, dynamic beam prescriptions are readily scaled with the set MU for the field. Control points do not need to be evenly spaced.

Any beam must be defined by at least two control points, an initial control point (control point 0) that defines the starting configuration and one defining the stop configuration. Control points defining intermediate configurations can be added.

In addition to dynamic beam collimation, this formalism can be used to define static and move-only beams or beam segments. A static beam segment is defined by two consecutive control points having the same parameter values but different percentage MU, whilst a move-only step can

be implemented by two control points with the same percentage MU but different parameter values. The beam is cut off during such move-only steps by inhibiting the radiation output from the linear accelerator. Combinations of static, dynamic and move-only segments may be mixed within a single beam prescription.

Note that although this control point formalism specifically supports one particular MLC control system, the same ideas can be used on other manufacturers' MLCs. Note also that, as will be shown below, the results generated by the algorithm described in this paper are also equally suitable for implementation via multiple static MLC fields.

Generation of discrete intensity-modulated beams by dynamic collimation

Ignoring for the moment restrictions on the allowed minimum leaf or collimator separation, the basic idea used to generate a discrete intensity-modulated beam by dynamic collimation can be illustrated by considering one isolated beam element. As the leading leaf or collimator jaw moves at constant speed to expose the element, a ramp down in intensity is delivered across the element. The element is then uniformly irradiated until the trailing leaf or jaw, moving at the same speed as the leading leaf, occludes the element and generates the necessary ramp-up in intensity needed to give a sharp, discrete primary exposure. This is basically the technique used by Hill *et al* (1997). Note that at the start and end of a row of these elements the leaf/jaw separation needs to be zero in order to provide a sharply-defined beam edge.

Generation of discrete intensity-modulated beams under minimum separation constraints

The process described above requires that the leaves or collimators can close in to zero separation at the start and end of the exposure. As has

been noted, this is not possible on all MLCs. However, according to the invention, it can by simulated by combining the motion of the MLC leaves and with that of the backup diaphragms (collimator jaws) in the dynamic beam prescription. In this case the positions of the leaves and backup diaphragms are offset such that the required gap between the MLC leaves is "hidden" under the backup diaphragm. This is illustrated at Figure 2(b).

Central blocking

Central blocking - that is, blocking a region inside the main field boundary - can also be achieved during a single dynamic exposure without having to close the leaves together, in which case the necessary leaf gap is again hidden under a backup diaphragm in the region to be blocked, as in Figure 2(b).

Implications of minimum leaf separation constraints for two-dimensional beam intensity modulation

Minimum leaf separation constraints, and in particular constraints on the allowed positioning of adjacent leaf pairs (Figure 2(a)), impose restrictions on the way in which a beam's modulation can be delivered. Specifically, when generating a two-dimensional (2D) intensity modulation within a beam a trailing leaf of one leaf pair may need to be moved forwards to shield a region so as to prevent it from being overexposed. Maintenance of the minimum leaf separation distance can then push a neighbouring leaf pair's leading leaf forwards, potentially leading to an overexposure here if only the MLC leaves are being used to generate the modulation. If, however, the backup diaphragm can be used as part of the dynamic collimation process then the leading leaf bank's backup diaphragm can be used to provide the necessary shielding, so allowing the leading leaf to move forwards whilst avoiding any overexposure. Alternatively, it may be possible to "slow down" the generation of the intensity distribution under the original

leaf pair so that the trailing leaf moves forward at a later point in the delivery sequence when it will then not give rise to a violation of the minimum leaf separation constraint with the neighbouring leaf pair. This is discussed in more detail below.

In general, then, under these minimum leaf separation constraints it is found that the derivation of the leaf motion for one pair of leaves cannot be considered in isolation from those of its neighbours because of the influence of "knock-on" effects such as that described above. Rather, it is necessary to consider together all involved leafs pairs and the profiles they are separately generating at all stages of the leaf motion generation. This then leads to a different approach to deriving MLC and diaphragm motion in which the derivation is made progressively control-point-by-control-point. In this way full account can be made of restrictions on leaf positioning (including adjacent leaf positioning) during the derivation and, as will be shown below, tongue-and-groove artefacts are then also easily removed. This approach is used in the algorithm described below.

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The Bixel Beam Intensity Modulation algorithm (Bixel BIM) is an iterative scheme to derive MLC leaf and backup diaphragm motion to deliver discrete beam-element (bixel) intensity modulated fields subject to restrictions on the allowed leaf separation. The algorithm progressively derives the motion of all involved leaf pairs and the MLC's backup diaphragms control-point-by-control-point as they track across the field rather than by considering each leaf pair's derivation separately, and includes a means of feeding back information on minimum leaf gap violations in order to derive deliverable dynamic prescriptions. It is assumed in what follows, without any loss of generality, that the leaves and diaphragms move from left to right across the field.

In deciding whether or not a bixel can be irradiated at any given control point two logical arrays (truth tables) are used within the algorithm. The first, *shield*, is defined for each bixel at each control point. It is set to "true" if a bixel must be shielded at the given control point; shielding may be by left or right MLC leaf or backup diaphragm. The second array, *right_diaphragm_shield*, is defined for each column in the field for each control point. If this is set to true for a given control point, then this entire column of bixels must be shielded by the right backup diaphragm (collimator jaw) at this control point. The status of these arrays is partly defined by the required intensity distribution itself (for example, any zero-intensity bixel must always be shielded), but are also continuously modified as the algorithm runs to correct for or prevent leaf collisions or minimum gap violations, to avoid overexposing regions of the field and to remove any tongue-and-groove artefacts within the derived motion. Note that, by definition, if *right_diaphragm_shield* is "true" for a column at any given control point, then so must *shield* for all bixels within that column.

The algorithm deals in integer units of bixel intensity, where one unit is equivalent to the intensity delivered in the time it takes for a leaf or diaphragm to travel the width of one bixel. The absolute magnitude of this intensity therefore depends on the width of the bixel, the maximum available leaf speed and on the dose rate used to deliver the field. MLC leaves and diaphragms are allowed to travel a distance of one bixel-width per control point and the minimum leaf separation is specified within the algorithm in units of bixel-widths. The mapping of a desired intensity distribution into bixel intensity units, and the control of the delivery resolution, is discussed in detail below. The minimum separation distance is expressed in units of bixel widths.

A schematic flow diagram of the algorithm is shown in Figure 4. A description of each of the main steps is given below.

Initialise leaf and diaphragm settings (control point 0)

At the start of the irradiation, the left leaves are set at the furthest left boundary of the field and the right leaves lie a distance equal to the minimum separation (in units of bixel-widths) into the field. The backup diaphragms are offset from these by a distance equal to this minimum bixel-unit separation so that the right diaphragm is at the left boundary and the left diaphragm is outside of the field.

Loop over control points

Starting from the first control point, use the current *shield* and *right_diaphragm_shield* settings to derive motion control-point-by-control-point as the MLC leaves and diaphragms track across the field. Thus, the steps below are carried out at each control print.

Set left backup diaphragm position

If any bixels in the column to the right of the current left backup diaphragm position requires at least one more control point to finish off its irradiation (found by checking the cumulative intensity so far delivered there), then the diaphragm must remain where it was at the previous control point. Otherwise, move it one bixel-width to the right.

Set left MLC leaf positions

A left (trailing) MLC leaf is only moved forward when the bixel after its current position is to be occluded at this control point (found by checking the cumulative intensity so far delivered there). If at least one more control point is needed to complete its irradiation, it maintains its position from the previous control point.

Set right MLC leaf positions

For each right MLC leaf, if the bixel that would be exposed by moving this leaf one bixel-width to the right is required to be shielded at this control point (i.e. *shield* is "true" for this bixel at this control point), *right_diaphragm_shield* is "false" and the left backup diaphragm has not been set to shield it at this control point, then it is necessary to keep the right leaf where it was at the previous control point. Otherwise, the leaf position for the current control point is set to one bixel-width further to the right than that at the last control point.

Set right backup diaphragm position

In general, the right backup diaphragm position at each control point is set to the position of the furthest-most right MLC leaf. However, it may be set less far into the field if the *right_diaphragm_shield* logical array is set to "true" for this column and control point, so that the diaphragm is being used to proving the necessary shielding here. Likewise, it may be necessary to hold the right diaphragm at the right field boundary to prevent overdosage outside of the field.

Check for collisions or minimum separation violations

Checks are made at this stage to ensure that the leaf and diaphragm positions, as set by the previous steps, do not result in violations of the minimum separation criteria. Checks must be made separately of the diaphragm separation and of the separation of the MLC leaves.

The backup diaphragm separation is checked first since their positioning can affect how MLC leaf separation violations are resolved. If it is less than the minimum allowed, then the right diaphragm is moved forward one bixel width unless it is acting to shield the column it is currently

above (as indicated by the *right_diaphragm_shield* logical array), in which case the left diaphragm must instead be set back one bixel width. If the left diaphragm has been moved back, it is then necessary to further check if this will then overexpose anything the diaphragm had been shielding. If this is found to be the case then *right_diaphragm_shield* is set to "true" for this column up until the current control point and the motion derivation restarted taking this new information into account.

Once the backup diaphragm positions have been checked and if necessary corrected, the MLC leaf positions can then be assessed. As noted previously (section 2), for designs such as the Elekta MLC the minimum separation requirement applies not only to each individual leaf pair but also to the positions of the neighbouring leaves, each of which must therefore be checked.

According to this example, a leaf separation check is made for each right leaf in turn. This check could of course be carried out for each left leaf.

If left and right leaves are within the minimum separation distance, a choice has to be made as to whether to move the left or right leaf to correct for this.

If the bixel the right leaf end is currently above does not need to be shielded at this control point or if it does need to be shielded and *right_diaphragm_shield* is also set, then the right leaf can be moved forwards.

If these conditions do not apply then a check is made to see whether it would be possible to prevent this constraint violation occurring by forcing the left leaf involved to arrive at this point later in the prescription (this can be done by inhibiting the motion of the associated right leaf). To do this, a

recursive check back through each column is made to find the first control point at which the bixel under the left leaf is exposed and assessing whether having the right leaf held back to shield this position would violate the minimum leaf separation requirement at that control point. If inhibiting the left leaf in this way is possible, the logical array *shield* is modified accordingly and the motion re-derived taking this into account. (For efficiency, the derivation may continue from the control point before the first change to *shield*).

If inhibiting the left leaf's progress in this way is not possible, then the right leaf must be moved forwards and the right diaphragm forced to shield the bixel (and hence the entire column) by setting *right_diaphragm_shield* to be true up until this control point and re-deriving the motion. As this results in a less efficient delivery scheme - the diaphragm is shielding everything beyond this point - this option is only used when inhibiting a right leaf if motion (above) is not possible.

Check that no right leaf has gone too far under the right diaphragm

After the minimum separation checks (above) and adjustments, a check is made to see if any right leaves under the right backup diaphragm are unnecessarily far under it. If they are and their settings for this control point can be adjusted without violating the minimum gap criteria, their positions are redefined. This step is done to minimise leakage through the backup diaphragm.

Check that no bixel is overexposed

Following adjustments required by minimum separation conditions, a check is made that no bixel is overexposed as a result of the current leaf and diaphragm settings - this can occur, for example, if a right leaf has been moved forward to prevent violation of minimum separation conditions. If

any bixel is overexposed, the *shield* logical array is set to "true" for this bixel for all control points up to the current one and the motion re-derived taking this updated information into account. Again, for efficiency, the derivation may continue from the control point before the first change to *shield*.

Check cumulative intensity delivered

A check is made to see if the correct cumulative intensities have been delivered to all bixels. If they have been, a check is optionally made of the intensities in the inter-leaf tongue-and-groove regions (below). If not, at least one more control point is needed and the loop over control points continues.

Check tongue-and-groove regions

A check is also optionally made of the intensities in the inter-leaf tongue-and-groove regions as each control point is derived. If any underexposure is found, this can be corrected for by inhibiting the motion of the most leading leaf pair (van Santvoort and Heijmen (1996)). Within the present algorithm, this is achieved by finding the earliest control point at which the associated bixel is exposed and setting *shield* to "true" for this bixel for N control points from this control point on, where the dose delivered over these N control points corresponds to the tongue-and-groove underexposure found. The motion is then re-derived taking this updated information into account and as before, the derivation may continue from the control point before the first change to *shield* was made.

It is noted, however, that the maintenance of the minimum leaf separation and associated collision avoidance routines tends to synchronise the leaf motion so that underdosage in the interleaf region is then not a major change to the delivery scheme and often does not involve any extra control points (and hence extra MU) for the total delivery.

Example application

The result of applying the above algorithm to the example distribution in Figure 1 is given in Figure 5, where the MLC configuration at each control point is shown. Regions in black are shielded by both an MLC leaf and backup diaphragm, regions in dark grey by an MLC leaf only and in light grey by a backup diaphragm only. The bixel (beam element) dimensions are 1cm x 1cm and a minimum leaf/diaphragm separation of 1cm specified. The closed configurations at the start and end of the delivery, required for a sharp field edge, can be clearly seen, as can the use of the backup diaphragms to provide shielding when the minimum leaf separation constraints limit leaf positioning. Note also that, as described above, leaves and diaphragms are restricted to move by only one bixel width per control point.

The above algorithm has been implemented to deliver discrete beam intensity modulation on Philips/Elekta SL25 with MLC. A schematic diagram of this implementation is given in Figure 6 and the main features discussed below.

Scaling the input intensity distribution

The input intensity distribution (which may of course be arbitrarily normalised) is scaled according to the "nominal dose" to be delivered by the field. This is done to control the resolution of the delivered intensity distribution and to ensure that the dynamic beam prescription, when delivered, will not require leaf speeds in excess of those the MLC is capable of (see below). The result can then be treated as a monitor unit distribution, specifying the MU each element in the beam should receive. Note, however, that the exact value used for the nominal dose is not critical (it is only used as a guide) since the beam prescription file is based on control points at percentage monitor unit points and is therefore scalable with set monitor

units.

Open field component delivery

In cases where the field is not centrally-blocked, an option exists within the implementation to deliver some or all of the base intensity level of the field by a single static field component. This would then allow portal imaging for positional verification of the patient as for conventional radiotherapy and could also allow for much of the field intensity to be delivered by a relatively large static field for which the dosimetry is more familiar and for which the effects of, for example, patient movement and leaf set-up errors are less critical. When this option is selected, the first two control points specify the static field (with the appropriate percentage MU). This is then followed by a move-only step during which the beam is off and the MLC leaves move to the left field boundary, after which the dynamic modulation is delivered in the subsequent control point steps.

Controlling the resolution of the delivered intensity distribution

The "basic" intensity resolution for delivery within this scheme is governed by the intensity delivered during the time it takes a leaf or diaphragm to cross the width of a beam element (bixel). This depends on the maximum allowed leaf speed, the dose rate at which the field is to be delivered and the element width. For example, for a 1cm-wide beam element, treating at 400MU/min with a maximum leaf speed of 1cm/sec results in a basic resolution for delivery of 6.67MU, i.e. ±3.3MU. The monitor unit distribution (i.e. the scaled intensity distribution) is then rounded to the nearest MU/bixel to create a bixel-intensity-unit array for use internally within the algorithm.

This resolution of delivery can, however, easily be improved by simply subdividing as necessary the beam elements in the original distribution along

the direction of leaf travel before rounding to give the bixel-intensity-unit array. In the example above, if the 1cm-wide elements were subdivided into 3.3mm elements, the resulting delivery resolution would be improved to ±1.1MU. The penalty paid for this is an increased number of control points required to define the dynamic prescription. It does not, however, affect the MLC delivery efficiency, i.e. the number of MU required to deliver the field.

In the algorithm described above, only the primary intensity has been considered - contributions from the finite transmission through the leaves and diaphragms, head scattered radiation and the variation of the primary intensity away from the central axis have not been included. This was intentionally done to provide a portable algorithm that was based on geometric concerns only and which was therefore independent of machine-to-machine variations and also of methods of calculating the above quantities. Instead, these additional factors can be included by embedding the algorithm within an iterative loop, such as the following (Convery and Webb (1997)):

1. Calculate the leaf and diaphragm motion using the above algorithm (geometry only).
2. Use this leaf motion to calculate the total intensity or dose under reference conditions, as required. If the difference between the calculated and desired values is greater than a set tolerance (or if continued iteration provides no improvement) then exit the iterative loop, otherwise proceed to step 3.
3. Calculate a modified input intensity distribution based on the difference between the calculated and desired values.
4. Use this modified intensity distribution as the input to the algorithm - repeat from step 1.

It is important to note that by separating dosimetric aspects from the actual derivation of the MLC motion the algorithm becomes independent of

the quantity we are actually concerned with modulating, which may for example variously be the total intensity of fluence "in-air" at the isocentre plane, the dose at peak depth at the isocentre plane, the dose at some reference depth under specified reference conditions, or some other quantity. The algorithm's application is also independent of the method used to calculate these quantities, so that it may therefore be used within different planning systems or software modules without modification, so ensuring portability and wider applicability.

Although the algorithm described was originally developed to generate dynamic collimation schemes for the delivery of fields with discrete beam intensity modulation, it can be seen from Figure 5 that the output can equally well be interpreted as a sequence of static MLC fields (defined by the control points configurations excluding those at the start and end of the motion). Since the original design was for a dynamic implementation, the beam-off time involved when stepping between each field configuration would be small. The only change required to the algorithm would be to write out each derived step as a static control point pair to be followed by a move-only step to the next field configuration. This may be necessary, for example, where full dynamic control of the MLC is not available.

Multiple static field delivery may also be preferred since this is a smaller step away from conventional radiotherapy delivery. Dosimetry of these beams is easier, as is their QA and verification, and they may therefore be more readily accepted clinically.

Although the techniques described herein (derivation of motion control-point-by-control-point, leaf collision correction/prevention routines, use of the backup diaphragms as part of the dynamic collimation process) were developed within the context of developing dynamic delivery schemes for discrete-modulated beams, they are also applicable to generating continuous (i.e. non-discrete) modulations.

Publications referred to in the above are as follows:

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CLAIMS

1. A method of delivering a radiotherapy treatment using a linear accelerator,

the linear accelerator comprising a source of radiation, the output of which is limited by a multi-leaf collimator and a further collimator comprising at least two diaphragms;

the method comprising the steps of:

notionally dividing the treatment area into an array of cells distributed along lines parallel to the movement directions of the leaves;

assigning an intended dose to each cell;

during irradiation, adjusting the position of the leaves so as to provide the intended dose to each cell, wherein during irradiation, the diaphragms are advanced beyond one or more leaves when necessary to maintain leaf separation and prevent overdosing.

2. A method according to claim 1 in which the diaphragms are normally maintained behind the outermost leaf, but are on occasions advanced beyond one or more leaves so that they provide the primary shield against dosing.

3. A method according to claim 2 in which the diaphragm is otherwise maintained immediately behind or close behind the outermost leaves.

4. A method substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

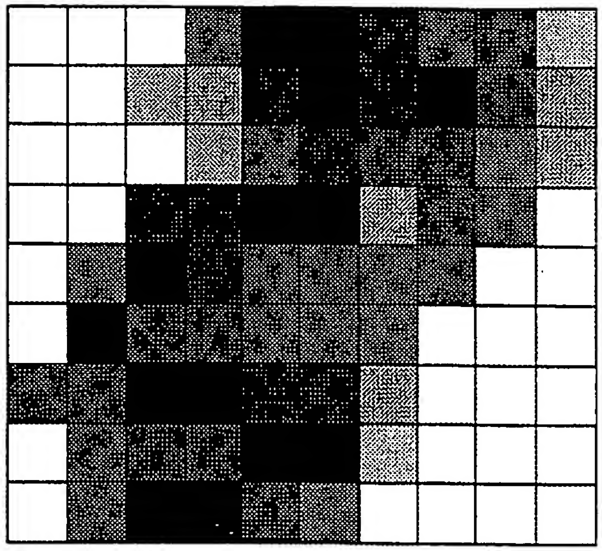


Fig 1(a)

0	0	0	6	10	10	9	7	8	1
0	0	2	3	9	10	9	10	8	3
0	0	0	3	7	9	8	8	5	3
0	0	9	9	10	10	3	8	7	0
0	5	10	9	7	7	6	7	0	0
0	10	8	8	7	6	5	0	0	0
8	8	10	10	9	9	3	0	0	0
0	7	8	8	10	10	1	0	0	0
0	7	10	10	8	5	0	0	0	0

Fig 1(b)

Fig 2(a)

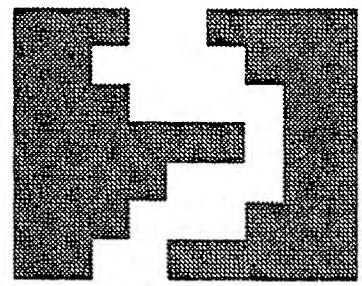
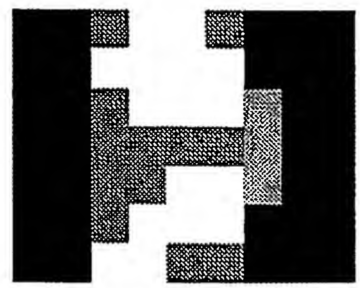


Fig 2(b)



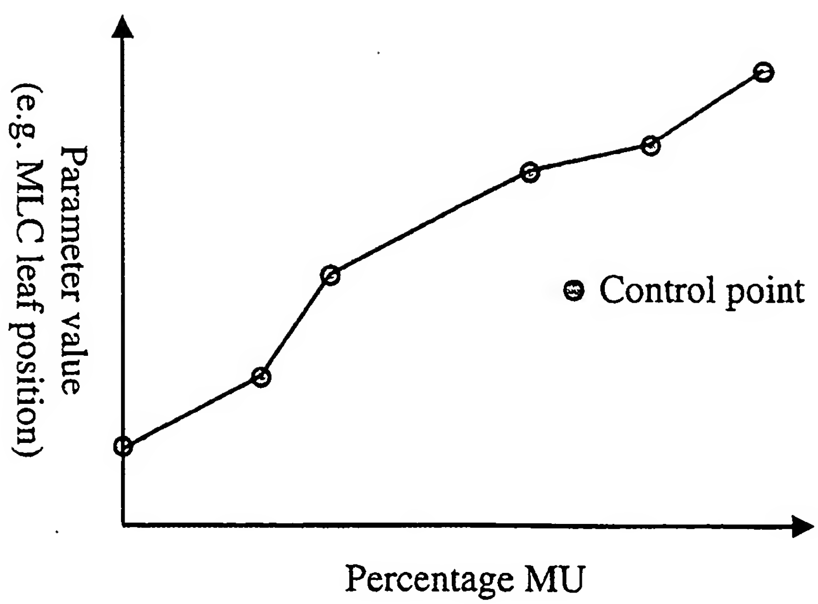


Fig 3

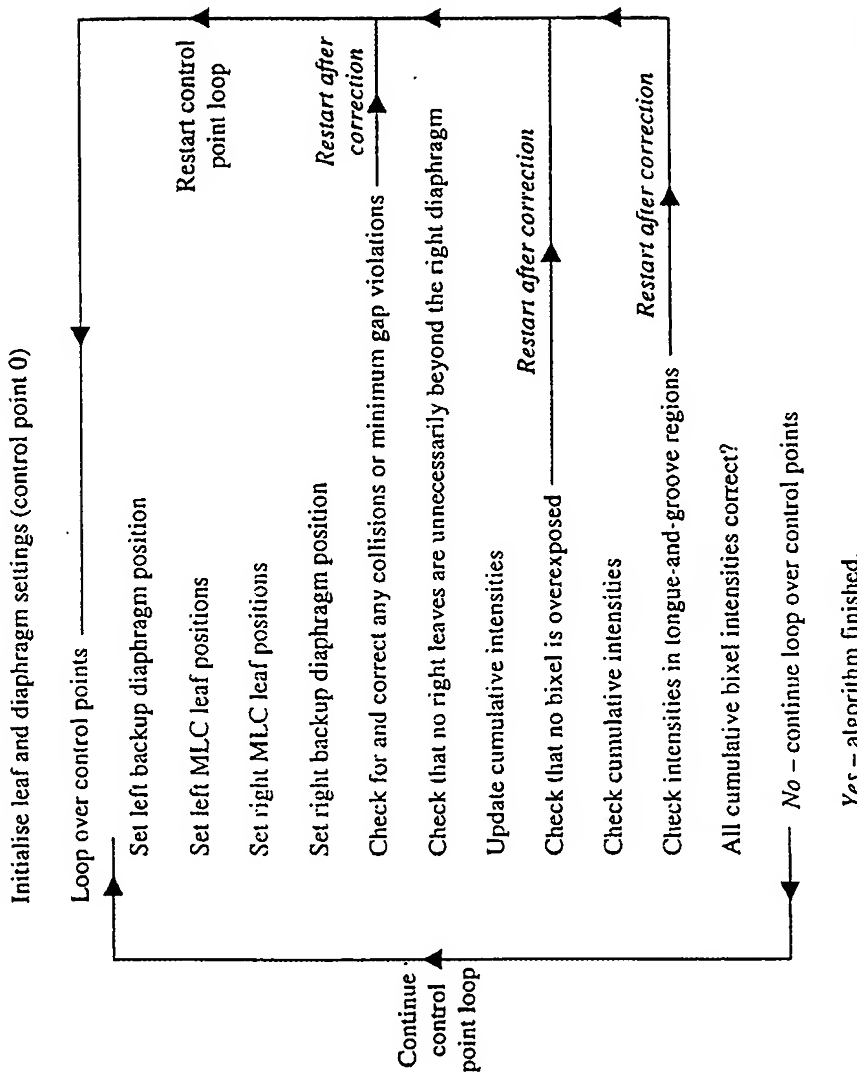

Initialise leaf and diaphragm settings (control point 0)
Loop over control points
Set left backup diaphragm position
Set left MLC leaf positions
Set right MLC leaf positions
Set right backup diaphragm position
Check for and correct any collisions or minimum gap violations
Check that no right leaves are unnecessarily beyond the right diaphragm
Update cumulative intensities
Check that no bixel is overexposed
Check cumulative intensities
Check intensities in tongue-and-groove regions
All cumulative bixel intensities correct?
No – continue loop over control points
Yes – algorithm finished.
Restart control point loop
Restart after correction
Restart after correction
Restart after correction
Continue control point loop

Fig 4

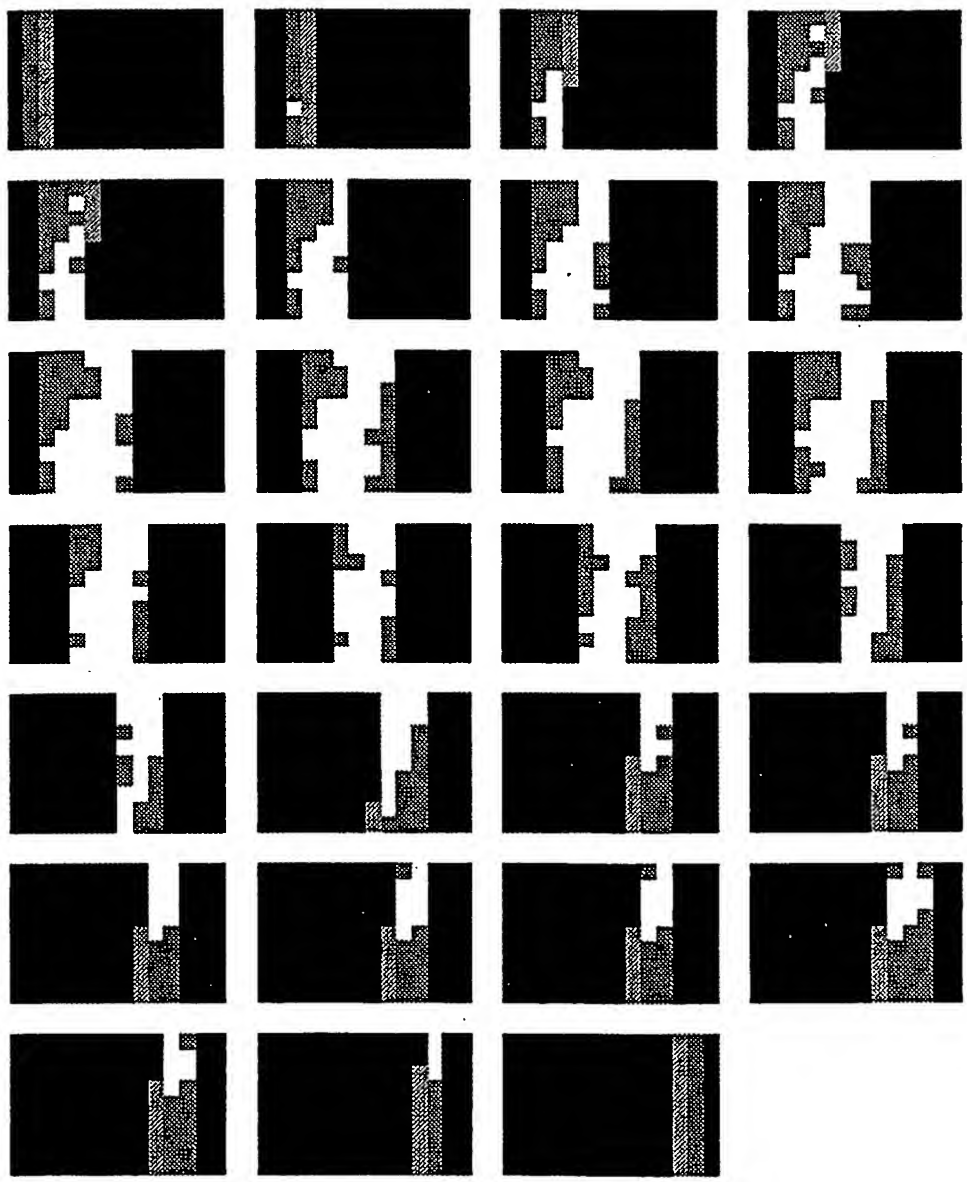


Fig 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/00886

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61N5/10 G21K1/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61N G21K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 556 874 A (VARIAN ASSOCIATES) 25 August 1993 see page 1, line 52 - line 59 see page 4, line 5 - line 20 see page 8, line 44 - line 49	
A	EP 0 314 214 A (PHILIPS NV) 3 May 1989 see column 4, line 46 - column 5, line 14; figure 2	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 June 1999	06/07/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Petter, E

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 99/00886

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 1-3
because they relate to subject matter not required to be searched by this Authority, namely:
Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy. The apparatus for carrying out the method has been searched.

2. [X] Claims Nos.: 4
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
clains includes reference to the drawimgs (Rule 6.2a).

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

In. onal Application No
PCT/GB 99/00886

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Form PCT/ISA/210 (patent family annex) (July 1992)